

Laser beam steering/shaping for free space optical communication

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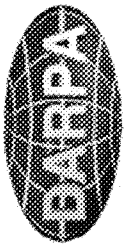
³NASA Glenn Research Center, Cleveland, OH 44135

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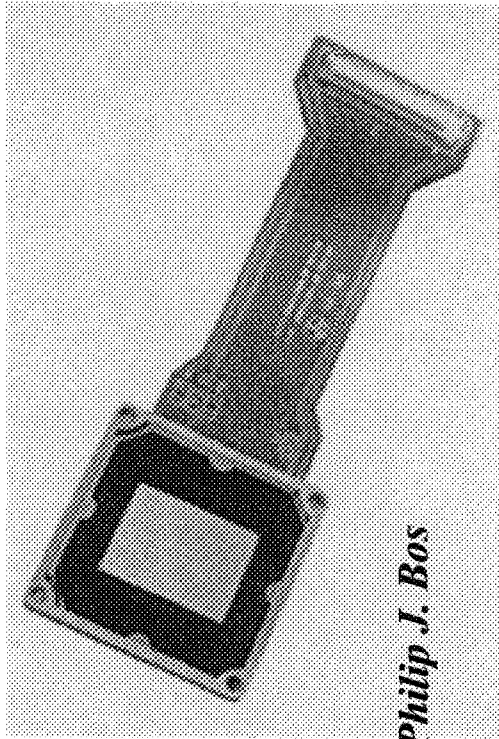
ABSTRACT

The 2-D Optical Phased Array (OPA) antenna based on a Liquid Crystal On Silicon (LCoS) device can be considered for use in free space optical communication as an active beam controlling device. Several examples of the functionality of the device include: beam steering in the horizontal and elevation direction; high resolution wavefront compensation in a large telescope; and beam shaping with the computer generated kinoform. Various issues related to the diffraction efficiency, steering range, steering accuracy as well as the magnitude of wavefront compensation are discussed.

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Laser beam steering/shaping for free space optical communication



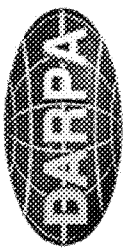
*Mark (Xinghua) Wang, Bin Wang, Philip J. Bos
Jim Anderson,*

John Pouch, Felix Miranda

Paul F. McManamon

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Outline

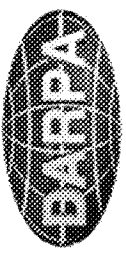
- Basic idea of 2-D Optical Phased Array (OPA)
- Beam steering of LCoS OPA
- Aberration control in large optics
- Beam shaping and manipulation

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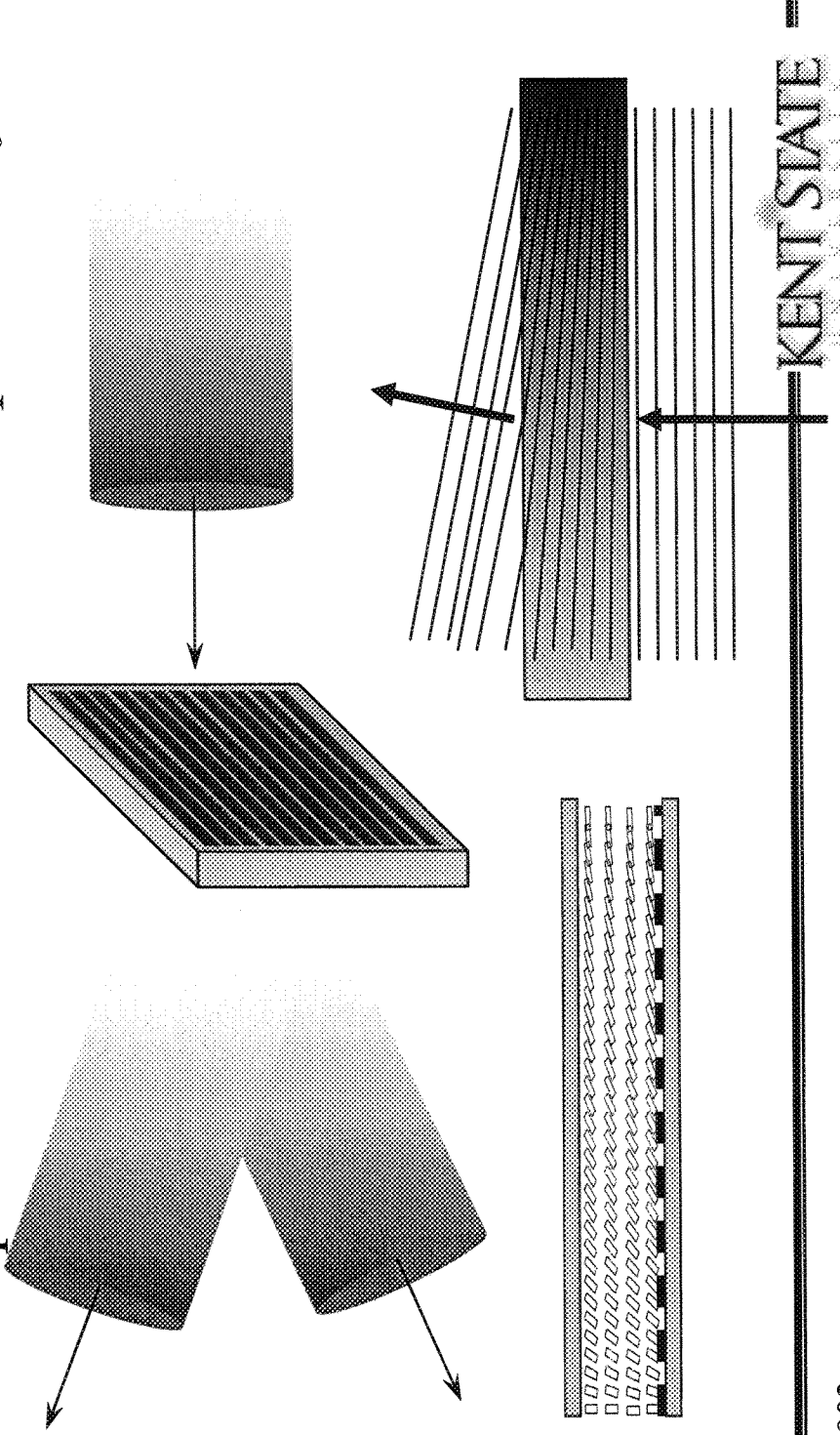


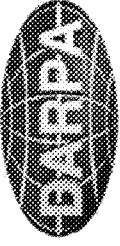
What is Optical Phased Array



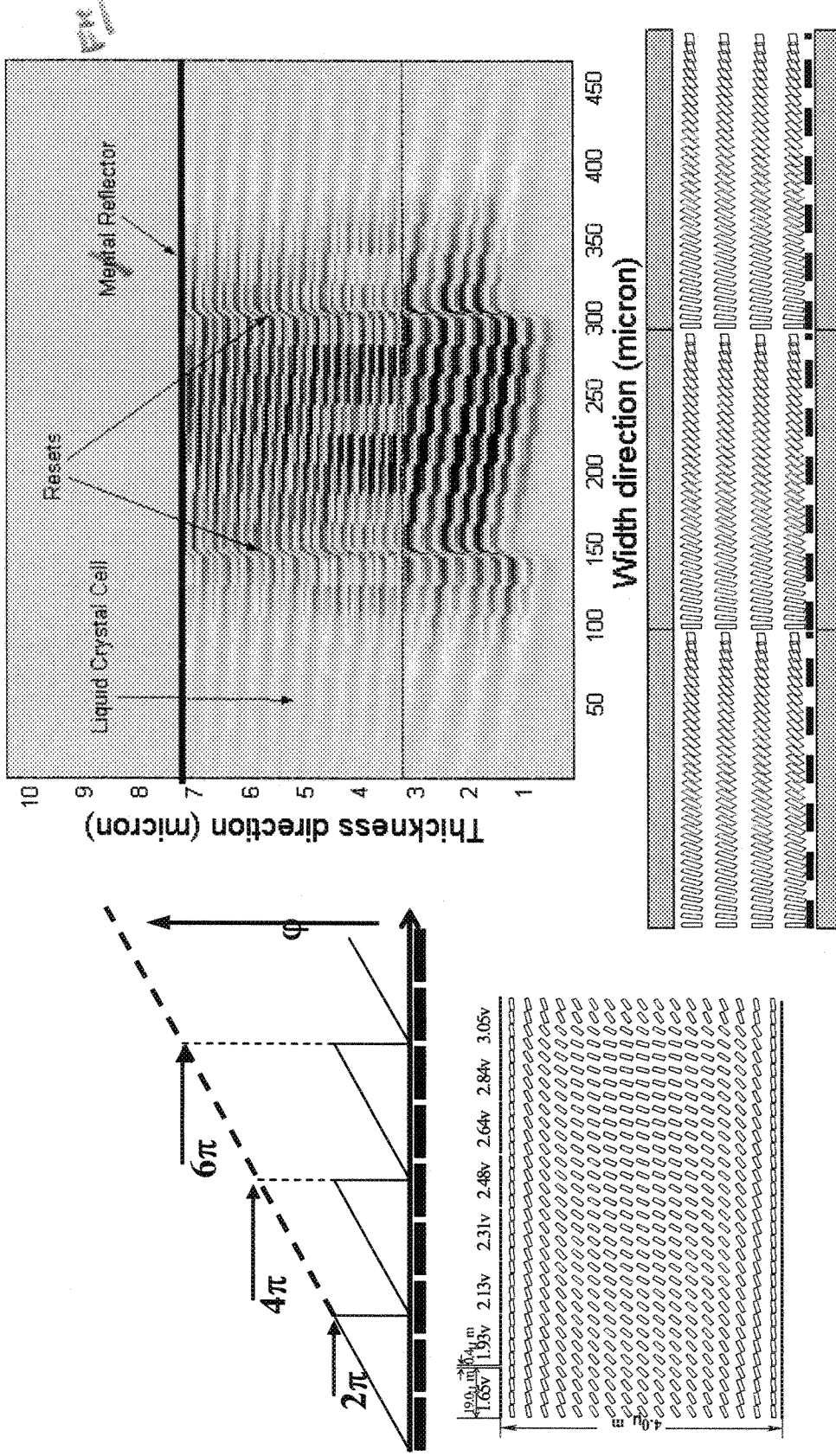
1-D Optical Phased Array:

line shape active element that can induce phase delay



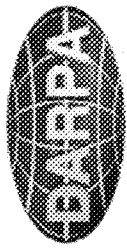


Light Propagation in LCoS



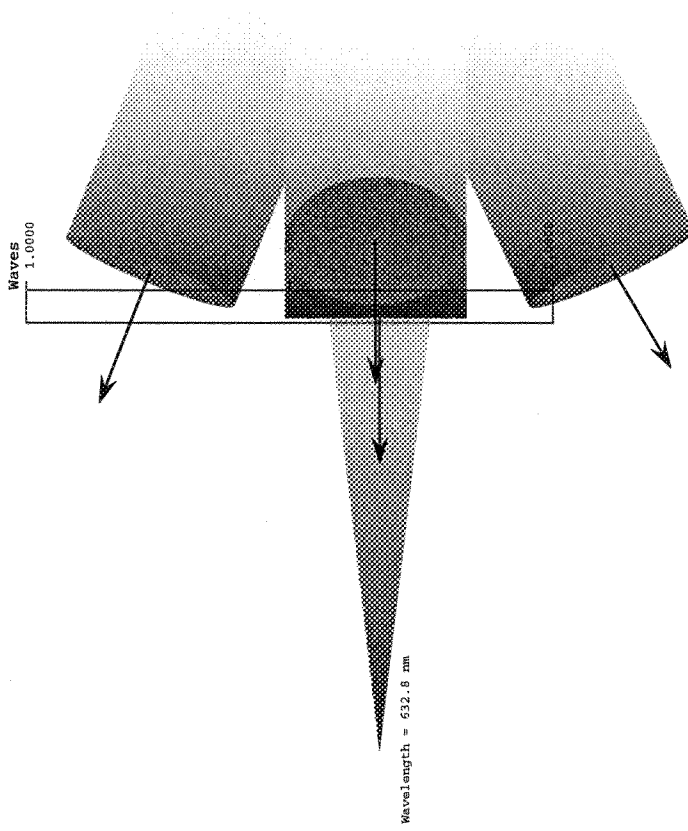
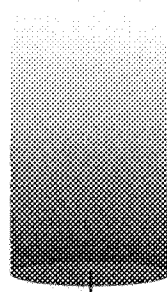
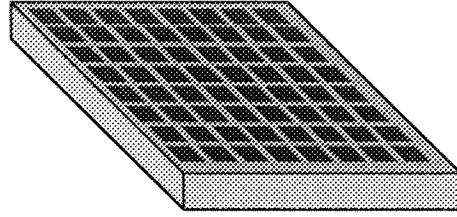
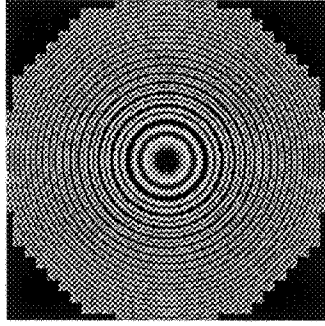
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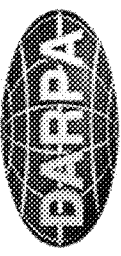
2-D Optical Phased Array

2-D array of independent
phase delay element



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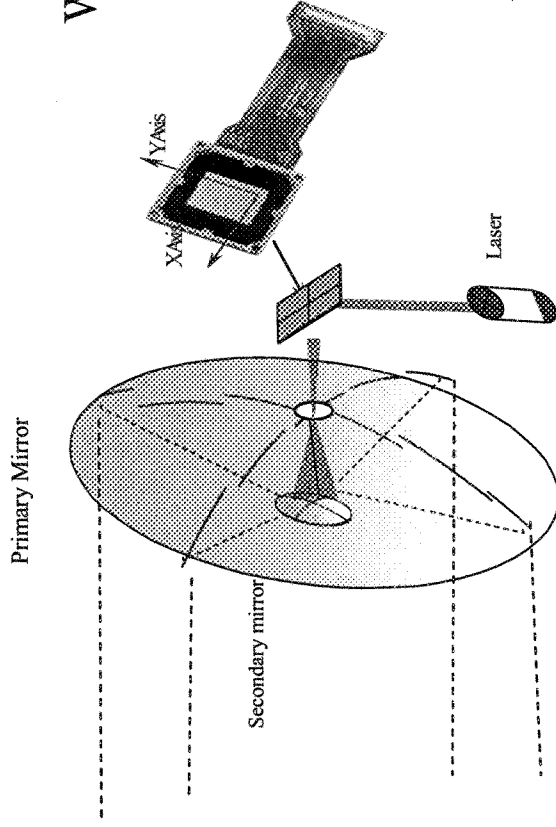
Importance of aberration control in lasercom system

NASA: Deep space **lasercom** system

Require: Sub-micro beam divergence: meter
scale primary mirror

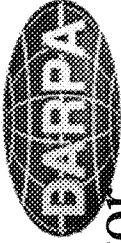
Want: Low Cost, Light Weight, Large optics,

Mechanical stability???

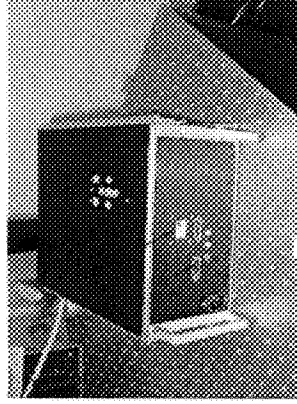
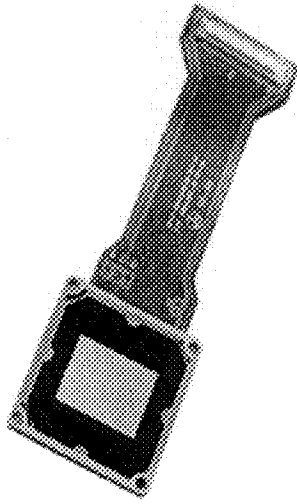


DARPA: Airborne lasercom system

Aberration introduced by window glass at
aircraft skin???

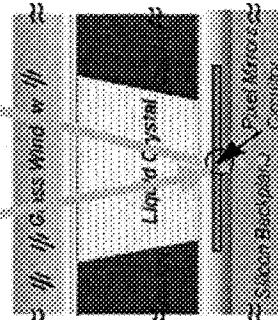


Liquid Crystal on Silicon Spatial light modulator



**Light
IN**

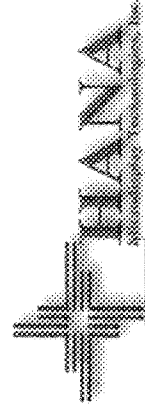
**Image OUT
(reflective devices)**



**Liquid Crystal Display
(LCD)**

IC Backplane

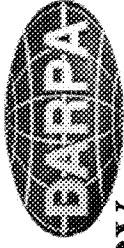
Resolution:	1024*768
Pixel Spacing:	19.4 μ m
Aperture:	20mm*15mm
Reflectivity:	80%
Filling factor:	96%
Speed:	50Hz, 25Hz, 5Hz
Effective stroke length:	0.7 μ m , 1.3 μ m, 2.5 μ m



ISO 9002

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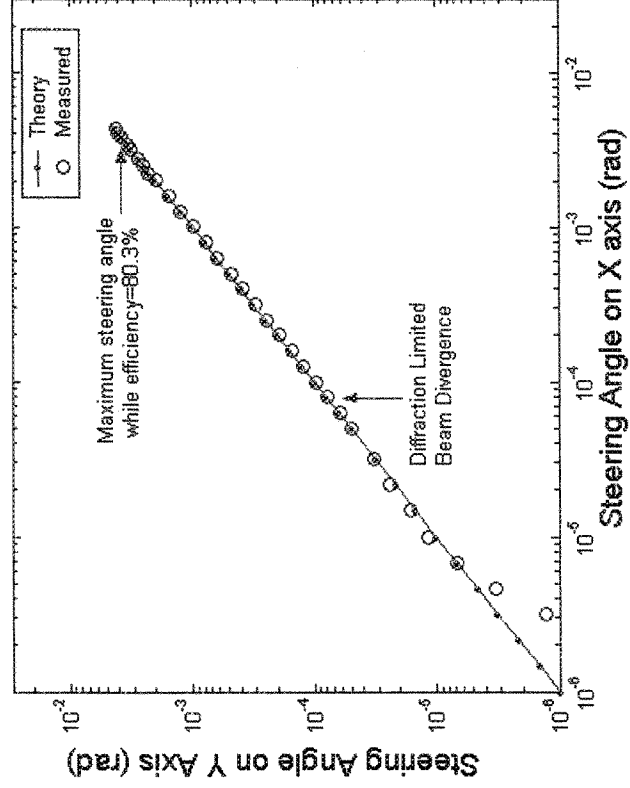
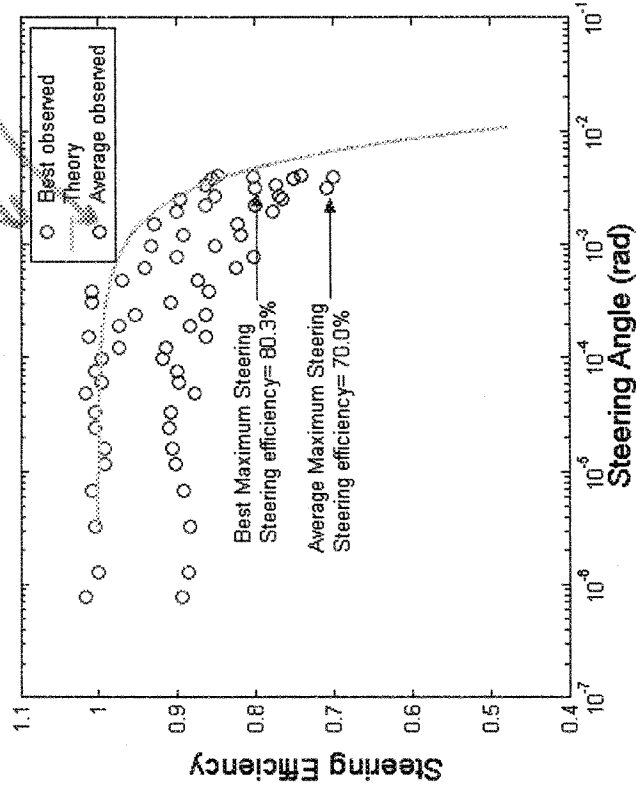
2D LCOS OPA steering efficiency/accuracy

Steering Range: ± 4 mrad (0.23°) on X and Y axis

Steering Accuracy: $10 \mu\text{rad}$ (1/10 diffraction limited beam divergence)

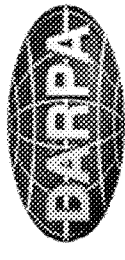
Steering Efficiency: $>80\%$

Symbols should be clearer & caption



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Optimization of LCoS OPA design

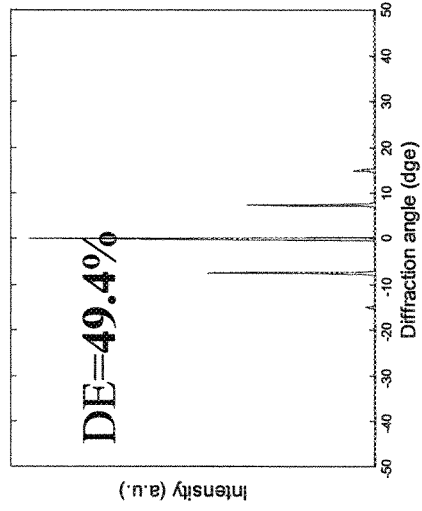
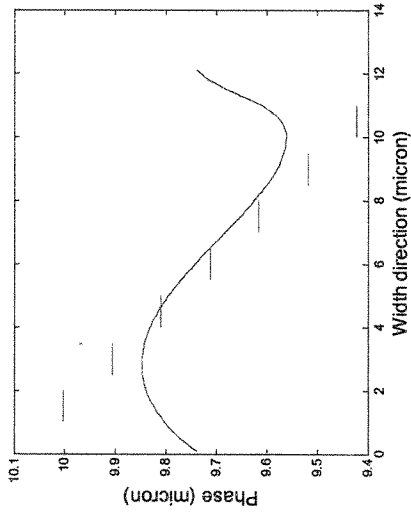
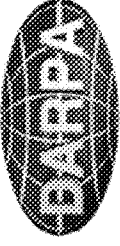
- An “ideal” OPA
- The effect of fringing fields in a real device
- Optimization of OPAs

Influence factor of diffraction efficiency of LC OPA

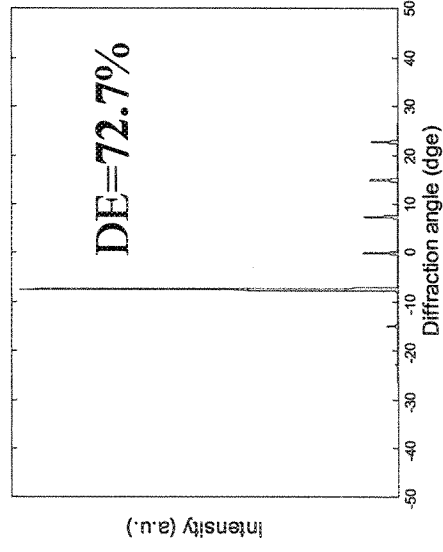
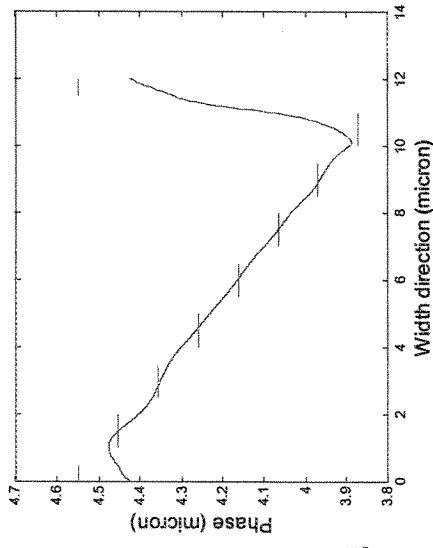
- Cell Thickness
- Voltage profile
- Grating period
- Inter-pixel gap (Electrode geometry)
- Optical axis (rubbing parallel/perpendicular to electrode in 1-D OPA case)
- $\Delta n \cdot d / \lambda$ value
- Pretilt angle
- Elastic constant of LC material



Wide angle beam steering LC OPA



Design optimization of LC OPAs



Wavelength= 1550 nm,

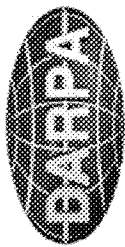
Steering angle $\pm 7.4^\circ$

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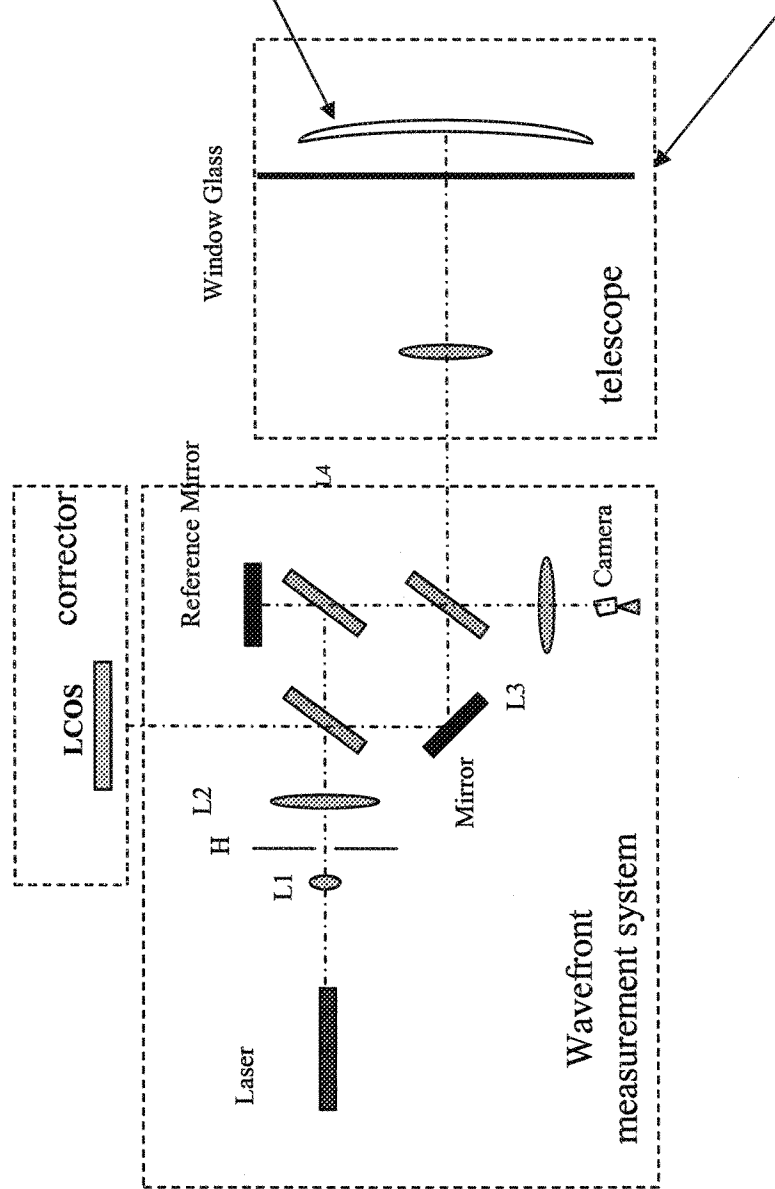
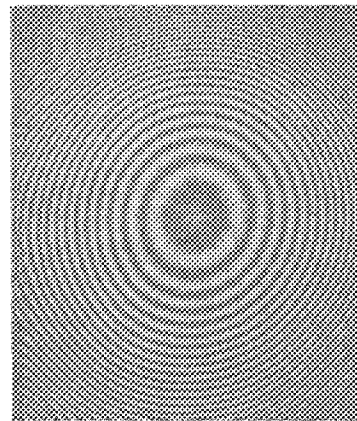
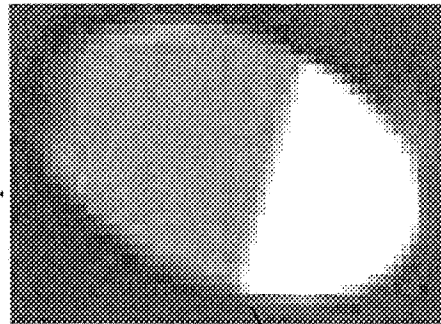
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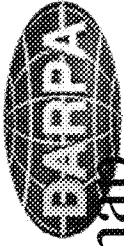


Aberration control in large optics



8 Inch diameter parabolic mirror





Zernike coefficient of the initial wavefront map

Before correction:

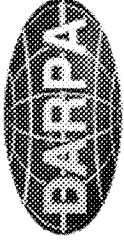
34 waves P-V, 8.5 wave R.M.S.

	Zernike term	Order	waves
1	Piston	0	7.781
2	Tilt	1	1.603
3	Tilt	1	-0.583
4	Focus	1	7.751
5	Astig.	2	2.097
6	Astig.	2	0.776
7	Coma	2	0.640
8	Coma	2	-0.130
9	Spherical	2	0.0783
10	Astig.	3	0.195
11	Astig.	3	-0.052
12		3	0.295
13		3	-0.031
14	Coma	3	0.056
15	Coma	3	-0.045
16	Astig.	3	-0.060

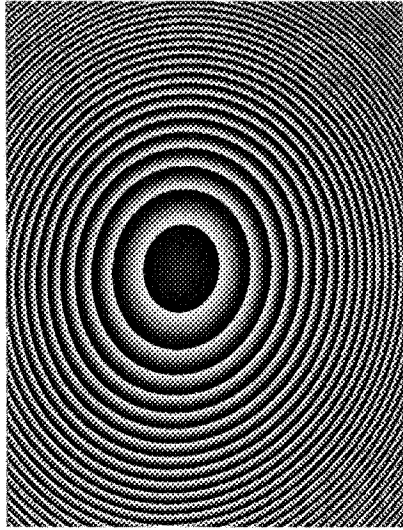


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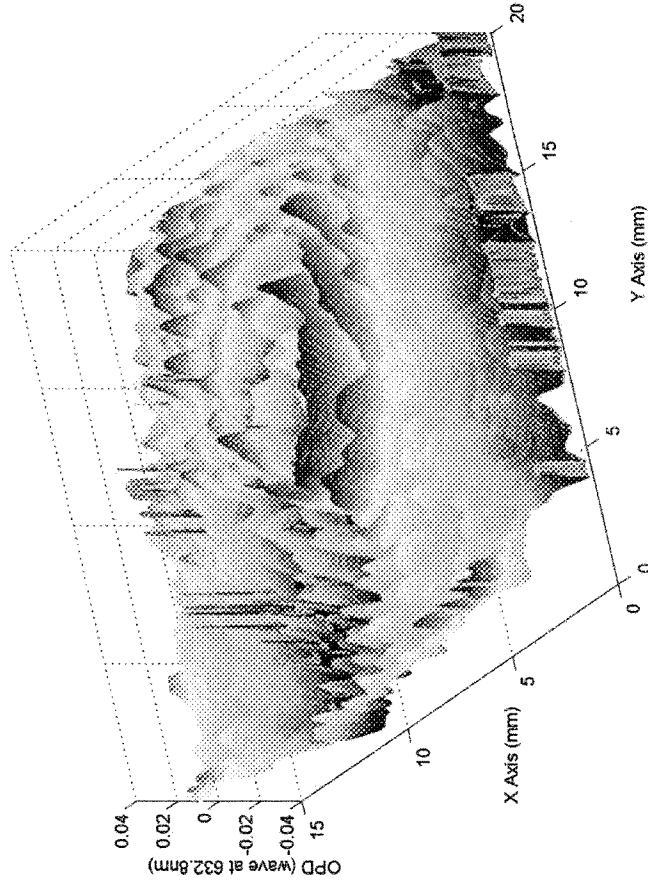
Residual wavefront aberration



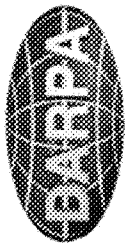
Residual aberration after correction:

1/10 wave P-V, 1/30 wave R.M.S.

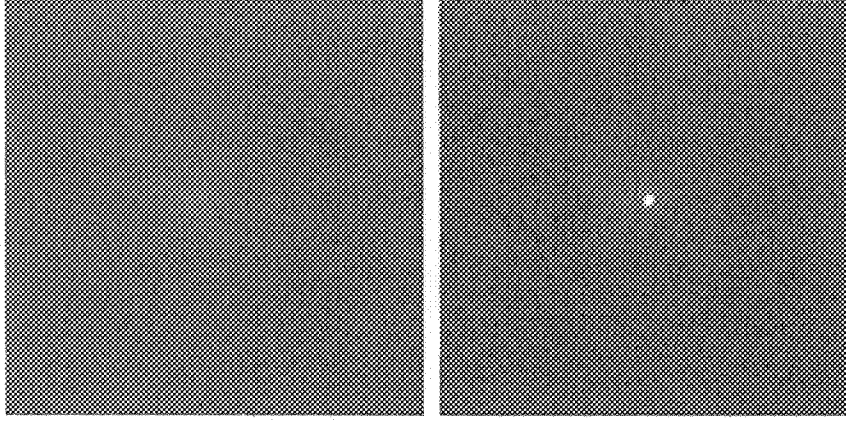
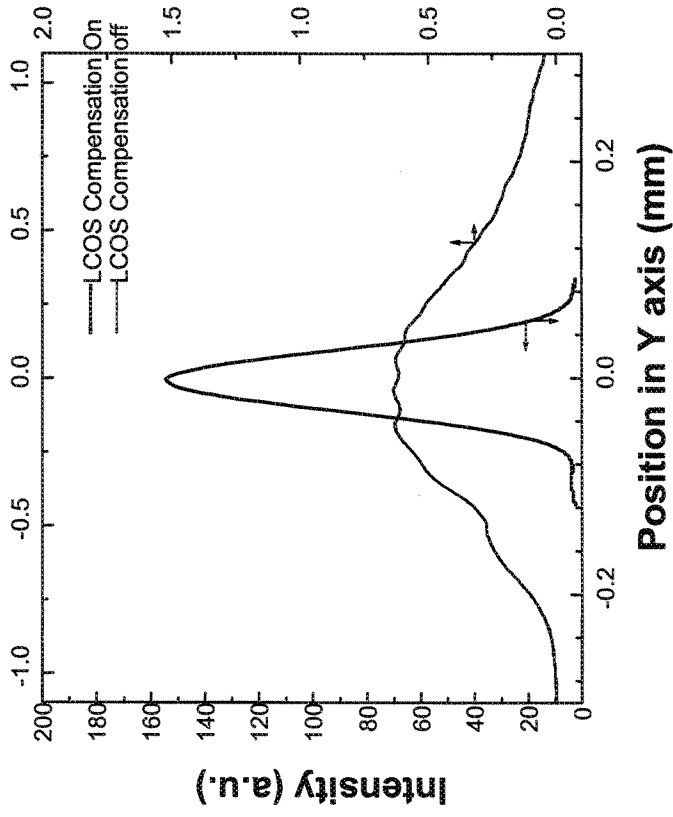
Diffraction limited performance!



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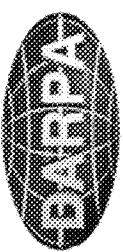
PSF after wavefront correction



Strehl ratio improvement factor=339

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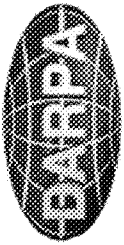


How much aberration can LCOS correct

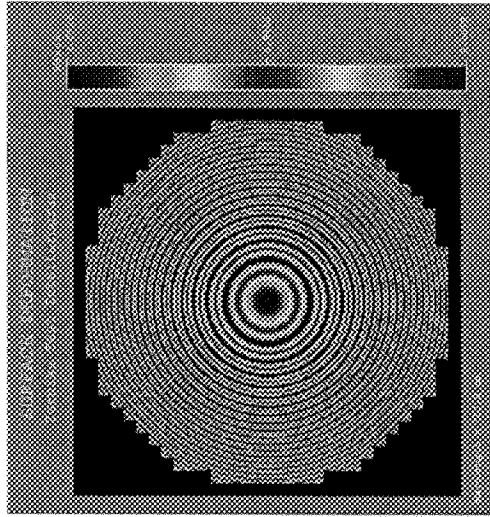
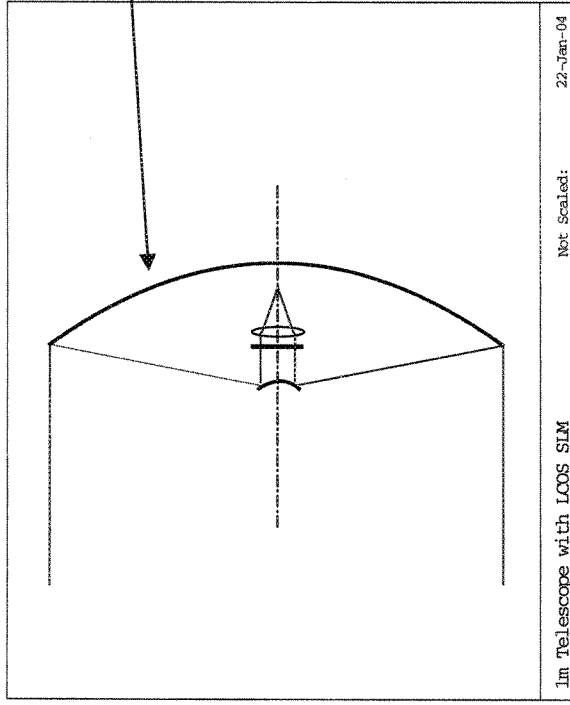
Requirements or assumption

- Given DE > 50%
- Aperture of the primary mirror = 1 meter
- Resolution of LCOS is 750*750

What is the total optical throughput



CODE V optical layout



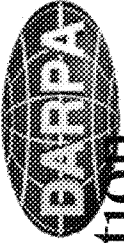
Initial wavefront aberration
on 1 meter clear aperture

P-V: 36 wave

R.M.S.: 20 wave

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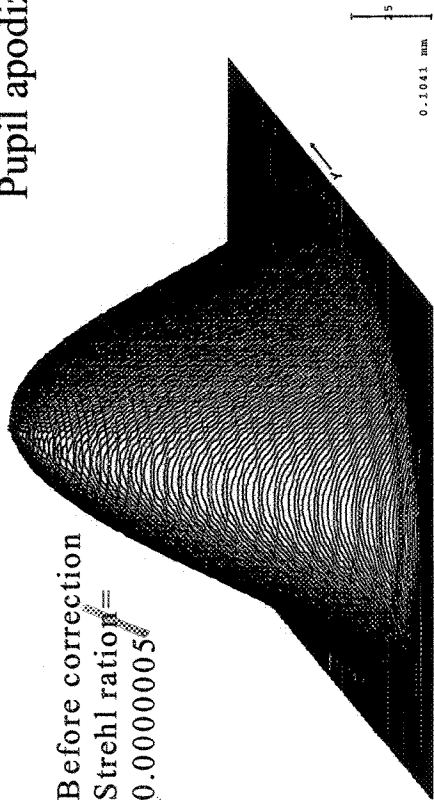


Comparison of PSF before and after correction

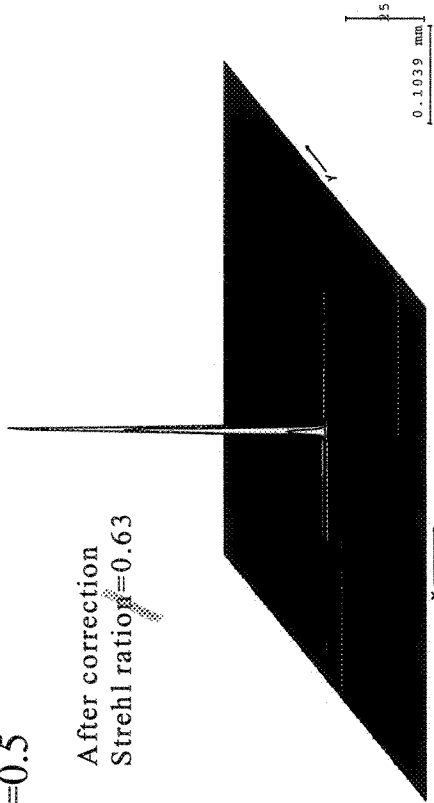
PSF obtained by Diffractive Beam Propagation,

Pupil apodization=0.5

Before correction
Strehl ratio=0.0000005



After correction
Strehl ratio=0.63



LCOS correct 1m Tele scope, Xinghua Wang	DIFRACTION INTENSITY SPREAD FUNCTION	WAVELENGTH WEIGHT
POSITION 1	FLD(0.00, 0.00)MAX:(0.0, 0.0)DEG	632.8 NM 1
31-Jul-03	DEFOCUSING: 0.000000 MM	

LCOS correct 1m Tele scope, Xinghua Wang	DIFRACTION INTENSITY SPREAD FUNCTION	WAVELENGTH WEIGHT
POSITION 1	FLD(0.00, 0.00)MAX:(0.0, 0.0)DEG	632.8 NM 1
31-Jul-03	DEFOCUSING: 0.000000 MM	

Simulated Strehl ratio improvement factor

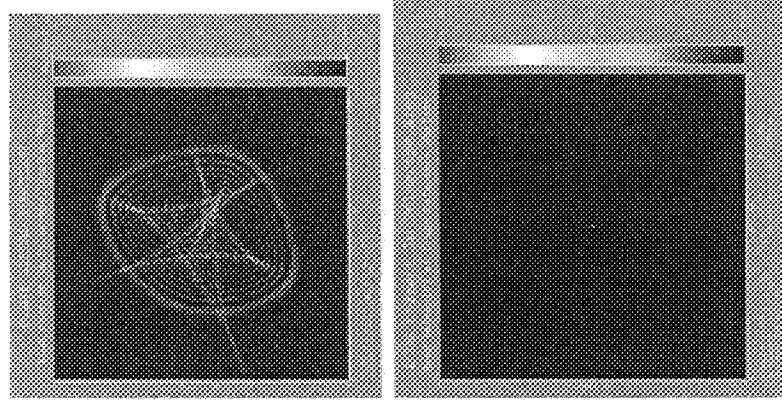
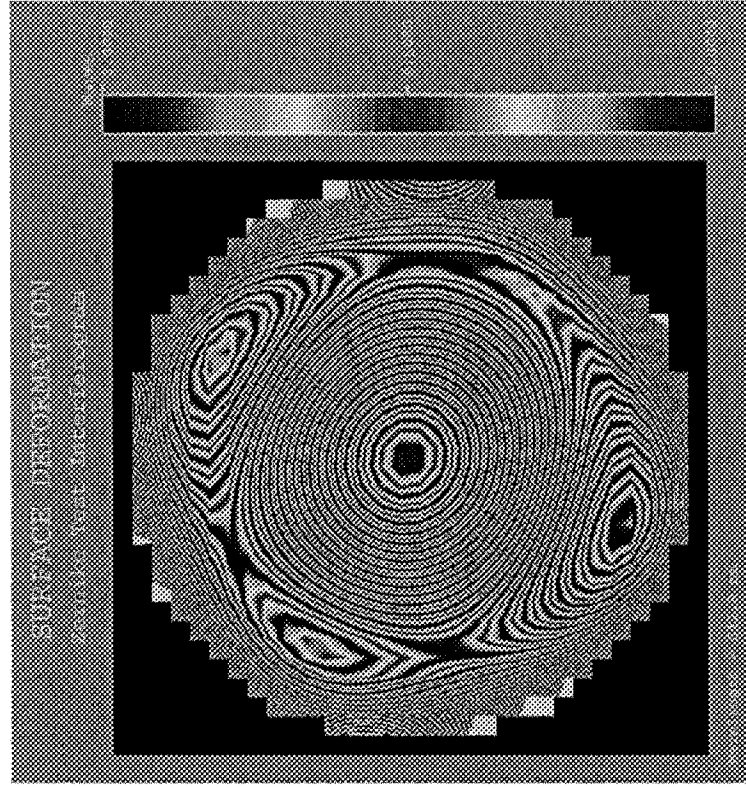
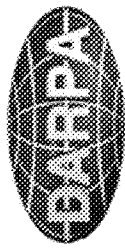
$$\gamma = 0.63 / 0.0000005 = 1.26 \times 10^6$$

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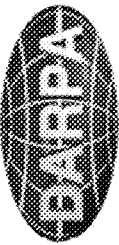
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Correction for high order aberration



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Maximum wavefront error can be corrected

$$\eta_{total} = \eta_r \eta_i \eta_c$$

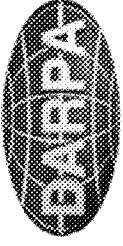
η_r ~~efficiency~~
reflectivity of LCOS

η_c efficiency due to the loss of imperfection in resets in liquid crystal phase profile

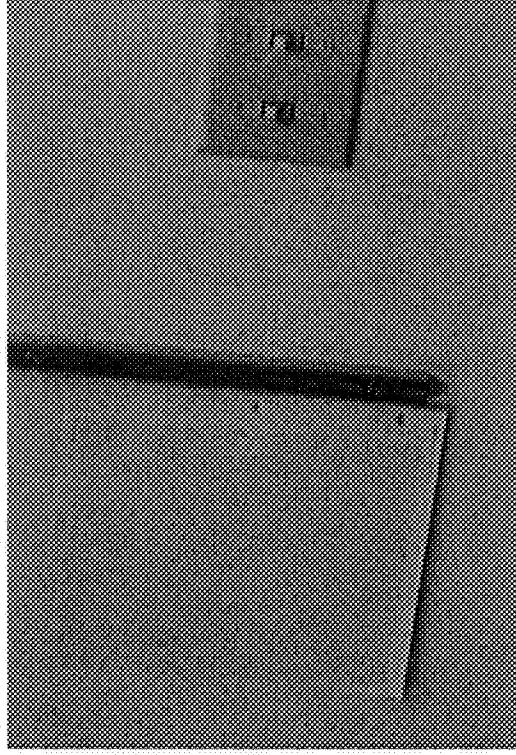
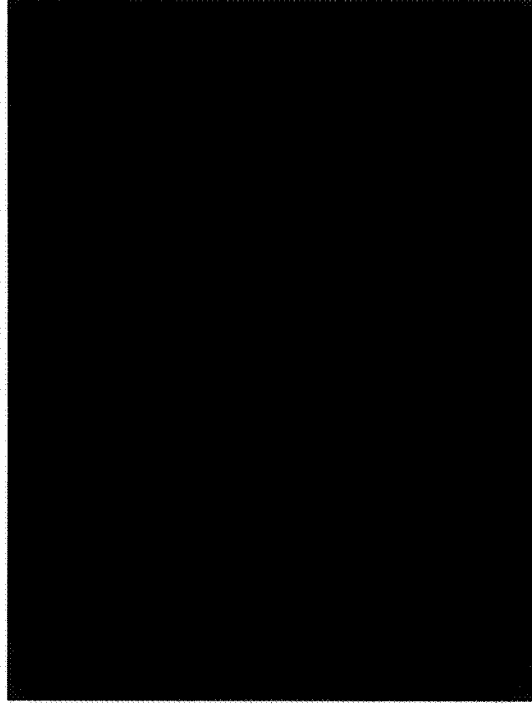
η_i efficiency for correction of wavefront aberration with an ideal piston phase plate

$$\eta_{total} = 90\% \times 90\% \times 0.63 = 0.51$$

Correct **48** waves P-V, or **20** waves R.M.S. of primary defocus with a 750 x 750 pixel LCoS 2-D OPA

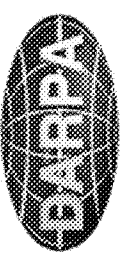


Compensation/ Steering/ focusing/Multiple beam pointing



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Conclusion

- 2-D LC OPA based on LCOS is very attractive for aberration correction in deployable large optics.
- Potentially lower the surface figure tolerance requirement for large optics.
- Provide active beam control for free space lasercom.